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(54) Polymeric material made from destructurelized starch and zein

(57) A polymeric material characterized in that said polymeric material is obtained by melting together a water-containing destructurelized starch and zein. The product may be shaped by injection moulding, blow moulding, extrusion, coextrusion, compression moulding or vacuum moulding to give sheets, films, and other shaped articles and is suitable for encapsulating pharmaceuticals or agriculturals.

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Polymeric material made from destructurized  
starch and zein

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The present invention refers to polymeric materials made from destructurized starch and zein.

It is known that natural starch which is found in vegetable products and which contains a defined amount of water, can be treated at an elevated temperature and in a closed vessel, thereby at elevated pressure, to form a melt. The process is conveniently carried out in an injection molding machine or extruder. The starch is fed through the hopper onto a rotating, reciprocating screw. The feed material moves along the screw towards the tip. During this process, its temperature is increased by means of external heaters around the outside of the barrel and by the shearing action of the screw. Starting in the feed zone and continuing in the compression zone, the particulate feed becomes gradually molten. It is then conveyed through the metering zone, where homogenization of the melt occurs, to the end of the screw. The molten material at the tip can then be further treated by injection molding or extrusion or any other known technique to treat thermoplastic melts, to obtain shaped articles.

This treatment, which is described in the European Patent Application No. 84 300 940.8 (Publication No. 118 240) yields an essentially deconstructurized starch. The reason for this being that the starch is heated above the melting and glass transition temperatures of its components so that they undergo endothermic transitions. As a consequence a melting and disordering of the molecular structure of the starch granules takes place, so that an essentially deconstructurized starch is obtained. The expression "deconstructurized starch" defined starch obtained by such thermoplastic melt formation.

Thermoplastic materials must be processed in the absence of water or volatile materials. Starch does not melt in the absence of water but decomposes at elevated temperature, i.e. around 240°C. It was therefore assumed that starch could not be used as a thermoplastic component together with hydrophobic water-insoluble polymeric materials such as water insoluble polymeric aminoacids, not only due to the mentioned factors but generally due to its chemical structure and its hydrophilic nature.

It has now been found that starch, containing a defined amount of water, when heated in a closed vessel as described above to form a melt of deconstructurized starch, can be processed together with zein, which is a natural water-insoluble polymeric protein, decomposing at higher temperature to yield a new material with very interesting properties.

The present invention refers to a polymeric material characterized in that said polymeric material is

obtained by forming a melt of a water-containing destructurized starch and zein.

The present invention refers to said polymeric material in the molten or in the solid form.

The present invention further refers to shaped articles made from said polymeric material.

The present invention further refers to a method of producing a modified destructurized starch in form of a melt by heating a starch having a water content of 5 to 30% by weight based on the starch/water composition in a closed volume to elevated temperatures thereby at elevated pressures for a time long enough to form a melt, characterized in that said process is carried out in the presence of zein admixed to said water containing starch.

The term "starch" as used herein includes chemically essentially non-modified starch as for example generally carbohydrates of natural, vegetable origin, composed mainly of amylose and/or amylopectin. They may be extracted from various plants, examples being potatoes, rice, tapioca, corn and cereals such as rye, oats, wheat. Preferred is starch made from potatoes or rice. It further includes physically modified starch such as gelatinized or cooked starch, starch with a modified acid value (pH), e.g. where acid has been added to lower its acid value to a range of about 3 to 6. Further is included starch, e.g. potato starch, in which the divalent ions like  $\text{Ca}^{+2}$  or  $\text{Mg}^{+2}$ -ions bridging the phosphate groups have been eliminated from this bridging function, i.e. the phosphate

bridges have essentially been broken down. It further includes pre-extruded starches.

It has recently been found, that starch with a water content within the range of about 5 to about 40% by weight based on the weight of the composition undergoes a "specific narrow endothermic transition" on heating to elevated temperatures and in a closed volume just prior to its endotherm change characteristic of oxidative and thermal degradation. This specific endothermic transition can be determined by differential scanning calorimetric analysis (DSC) and is indicated on the DSC-diagram by a specific relatively narrow peak just prior to the endotherm change characteristic of oxidative and thermal degradation. This peak disappears as soon as the mentioned specific endothermic transition has been undergone. The term "starch" includes also treated starches wherein said specific endothermic transition has been undergone.

Zein is a vegetable polymeric protein of corn gluten soluble in alcohol but not in water. To use such a material in an injection molding process together with water-containing starch has never been described and it is surprising that a uniform product with new and interesting properties is obtained.

The ratio of destructurized starch to zein is preferably 50:50 to 99.5:0.5. It is however preferred that the destructurized starch contributes noticeably to the properties of the final material. Therefore, it is preferred that the destructurized starch is present in an amount of at least 70% and more preferably in the range of 80% to 99,5% by weight of the entire

composition. A preferred ratio of starch to zein is 95:5 to 99:1.

A mixture of 5 to 10% by weight of the zein and 95 to 90% of the destructurized starch shows interesting variations of the properties of the obtained material.

The starch can be mixed with the zein and then heated for destructurization to form a melt. The starch can also be destructurized and granulated before it is mixed with the zein. In the latter case both components should have preferably a comparable granular size.

The essentially destructurized zein containing starch/water composition resp. granules have a preferred water content in the range of about 10 to 20% by weight of the composition, preferably 12 to 19% and especially 14 to 18% by weight, calculated to the weight of the composition.

In order to destructurize the starch, it is suitably heated in a screw barrel of an extruder for a time long enough to effect destructurization. The temperature is preferably within the range of 120°C to 190°C, preferably within the range of 130°C to 190°C depending on the type of starch used. For this destructurization, the starch material is heated preferably in a closed volume. A closed volume can be a closed vessel or the volume created by the sealing action of the unmolten feed material as happens in the screw of injection molding or extrusion equipment. In this sense the screw barrel of an injection molding machine or an extruder is to be understood as being a closed vessel. Pressures created in a closed vessel

correspond to the vapour pressure of water at the used temperature but of course pressure may be applied and/or generated as normally occurs in a screw barrel. The preferred applied and/or generated pressures are in the range of the pressures which occur in extrusion and are known per se, i.e. from zero to  $150 \times 10^5 \text{ N/m}^2$  preferably from zero to  $75 \times 10^5 \text{ N/m}^2$  and most particularly from zero to  $50 \times 10^5 \text{ N/m}^2$ . The obtained destructureized starch is granulated and ready to be mixed with the zein to obtain the granular mixture of the destructureized starch/zein starting material to be fed to the screw barrel.

If the starch/zein mixture is prepared before destructureization, process conditions are the same with the exception that the temperature preferably does not exceed  $180^\circ\text{C}$ . Preferably the mixture is first extended and granulated, but it is possible to directly form it into the desired shaped article.

Within the screw barrel the granular mixture is heated to a temperature which is generally within the range of about  $100$  to  $180^\circ\text{C}$ , preferably within the range of about  $120$  to  $180^\circ\text{C}$  and especially at about  $140$  to  $175^\circ\text{C}$ .

The minimum pressure for forming the melt corresponds to the water vapour pressure produced at these temperatures. The process is carried out in a closed volume as explained above, i.e. in the range of the pressures which occur in extrusion processes and are known per se, e.g. from zero to  $150 \times 10^5 \text{ N/m}^2$  preferably from zero to  $75 \times 10^5 \text{ N/m}^2$  and most particularly from zero to  $50 \times 10^5 \text{ N/m}^2$ .



When forming a shaped article by extrusion the pressures are preferably as mentioned above. If the melt according to this invention is e.g. injection molded, the normal range of injection pressures used in injection molding is applied, namely from  $300 \times 10^5 \text{ N/m}^2$  to  $3.000 \times 10^5 \text{ N/m}^2$  preferably  $700 \times 10^5 - 2200 \times 10^5 \text{ N/m}^2$ .

The starch material of the present invention may contain or may be mixed with additives such as extenders, lubricants, plasticizers and/or coloring agents.

These additives may be added before the destructureizing step or after this step, i.e. mixed with the solid granules of the destructureized starch.

Such additives are extenders of different kinds, e.g. gelatin, vegetable proteins such as sunflower protein, soybean proteins, cotton seed proteins, peanut proteins, rape seed proteins, blood proteins, egg proteins, acrylated proteins; water-soluble polysaccharides such as:

alkylcelluloses hydroxyalkylcelluloses and hydroxyalkylalkylcelluloses, such as: methylcellulose, hydroxymethylcellulose, hydroxyethylcellulose, hydroxypropylcellulose, hydroxyethylmethylcellulose, hydroxypropylmethylcellulose, hydroxybutylmethylcellulose, celluloseesters and hydroxyalkylcelluloseesters such as: celluloseacetylphthalate (CAP), Hydroxypropylmethylcellulose (HPMCP); carboxyalkylcelluloses, carboxyalkyl-alkylcelluloses, carboxyalkylcelluloseesters such as:

carboxymethylcellulose and their alkalimetal salts; water-soluble synthetic polymers such as: polyacrylic acids and polyacrylic acid esters, polymethacrylic acids and polymethacrylic acid esters, polyvinylacetates, polyvinylalcohols, polyvinylacetatephthalates (PVAP), polyvinylpyrrolidone, polycrotonic acids; suitable are also phthalated gelatin, gelatin succinate, crosslinked gelatin, shellac, water soluble chemical derivatives of starch, cationically modified acrylates and methacrylates possessing, for example, a tertiary or quaternary amino group, such as the diethylaminoethyl group, which may be quaternized if desired; and other similar polymers.

Such extenders may optionally be added in any desired amount preferably up to and including 50 %, preferably within the range of 3 % to 10 % based on the weight of all components.

Further additives are inorganic fillers, such as the oxides of magnesium, aluminum, silicon, titanium, etc. preferably in a concentration in the range of about 0.02 to 3 % by weight preferably 0.02 to 1 % based on the weight of all components.

Further examples of additives are plasticizers which include polyalkylene oxides, such as polyethylene glycols, polypropylene glycols, polyethylene-propylene glycols; organic plasticizers with low molecular weights, such as glycerol, glycerol monoacetate, diacetate or triacetate; propylene glycol, sorbitol, sodium diethylsulfosuccinate, triethyl citrate, tributyl citrate, etc., added in concentrations

ranging from 0.5 to 15 %, preferably ranging from 0.5 to 5 % based on the weight of all the components.

Examples of coloring agents include known azo dyes, organic or inorganic pigments, or coloring agents of natural origin. Inorganic pigments are preferred, such as the oxides of iron or titanium, these oxides, known per se, being added in concentrations ranging from 0.001 to 10 %, preferably 0.5 to 3 %, based on the weight of all the components.

The sum of the plasticizer and water contents should preferably not exceed 25 %, and should most preferably not exceed 20 %, based on the weight of all the components.

There may further be added compounds to improve the flow properties of the starch material such as animal or vegetable fats, preferably in their hydrogenated form, especially those which are solid at room temperature. These fats have preferably a melting point of 50°C or higher. Preferred are Triglycerides with C<sub>12</sub> -, C<sub>14</sub> -, C<sub>16</sub> -, and C<sub>18</sub> - fatty acids.

These fats can be added alone without adding extenders or plasticizers.

These fats can advantageously be added alone or together with mono- and/or diglycerides or phosphatides, especially lecithin. The mono- and diglycerides are preferably derived from the types of fats described above, i.e. with C<sub>12</sub> -, C<sub>14</sub> -, C<sub>16</sub> -, and C<sub>18</sub> - fatty acids.

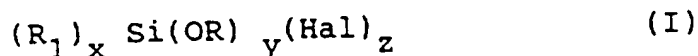
The total amounts used of the fats mono-, diglycerides and/or lecithins are up to 5 % and preferably within the range of about 0.5 to 2 % by weight of the deconstructurized starch components.

It is further recommended to add silicon dioxide or titanium dioxide in a concentration of about 0.02 to 1 % by weight of the deconstructurized starch components.

It is of further advantage to add an organosilane to the deconstructurized starch, i.e. before or after deconstructurization, to modify its surface in such a way that its compatibility with the zein is improved. It further reduces the hydrophilic nature of the starch. Preferred are organosilanes capable of reacting with a hydroxylgroup.

The amount of reactive silane added depends on the number of reactive sites on the silane as well as on the degree of modification to be incorporated to the starch material. In general a concentration of one molecule of silane to 1000 anhydro glucose units (AGU) will already show a visible effect, although higher concentrations between 2 to 50 and preferably 5 to 20 molecules of silane to 1000 AGU are preferred. It depends on the nature of silane used and is easily optimized by the expert skilled in the art.

Preferred silanes are those of the formula



wherein

$R_1$  is independently alkyl ( $C_1 - C_8$ ), substituted alkyl ( $C_1 - C_4$ ), vinyl or phenyl, wherein the alkyl substitution is selected from chlorine,  $-NH_2$ , substituted amino, an unsaturated bond, or a rest carrying an epoxigroup; R is hydrogen or alkyl ( $C_1 - C_4$ ) or acyl ( $C_1 - C_4$ ), preferably methyl or ethyl, Hal is halogen, preferably chlorine, bromine, preferably chlorine;

x is 1, 2 or 3 preferably 1 or 2;

y is zero, 1, 2 or 3;

z is zero, 1, 2 or 3,

the sum of  $y + z$  is 1, 2 or 3, preferably 2 or 3; and

the sum of  $x + y + z$  is 4.

Preferred silanes are those wherein x is 1 or 2, preferably 1; R is methyl or ethyl, preferably methyl and  $R_1$  is methyl, ethyl, propyl, butyl and z is zero if mainly water-repellency shall be incorporated to the starch molecule.

If other properties should be incorporated, the  $R_1$  is preferably substituted, i.e. for additional crosslinking  $R_1$  is substituted e.g. with an epoxy group.

Examples for such silanes are

methyltriethoxysilane, ethyltrimethoxysilane,  
propyltrimethoxysilane, butyltrimethoxysilane,  
chloromethyltriethoxysilane,  
3-aminopropyl-trimethoxysilane,  
4-aminobutyldimethylmethoxysilane,  
vinyltriethoxysilane, allyltrimethoxysilane,  
p-chlorophenyltriethoxysilane, as well as the

corresponding triethoxycompounds or the corresponding dialkoxy or monoalkoxycompounds containing one resp. two more methylgroups. Further compounds of formula (I) are 3-glycidoxypopyltrimethoxysilane, trimethylsilylacetic acid, triethylsilanol, tri-n-propylsilanol, diphenylhydroxysilane, trimethylchlorosilane, diphenylmethylchlorosilane, tert-butyldimethylchlorosilane, triethylchlorosilane, propyldimethylchlorosilane, allyldimethylchlorosilane, wherein the alkoxycompounds with a saturated alkylrest are the preferred ones.

The silane is simply added uniformly to the starch material before transforming it into a melt by any known method, optionally using a solvent which can be evaporated. In this case special care has to be taken to keep the water content of the starch material within the prescribed range.

Optionally the pH is adjusted to lower or higher values than 7 or a catalyst like organometallic esters such as butyl-titanate which promotes the reaction between hydroxyl group and the Si-OR bond is added.

The materials described herein above form on heating and in a closed vessel a melt with thermoplastic properties, i.e. under controlled water-content and pressure condition. Such a melt can be used in various techniques just like thermoplastic materials. These techniques include injection molding, blow molding, extrusion and coextrusion (rod, pipe and film extrusion), compression molding, to produce known articles as produced with these techniques. These articles include bottles, sheets, films, packaging

materials, pipes, rods, laminates, sacks, bags, pharmaceutical capsules, granules or powders.

Such modified starch may be used as a carrier material for active substances, and may be mixed with active ingredients such as pharmaceuticals and/or agriculturally active compounds such as insecticides or pesticides. The resulting extruded material can be granulated or worked to a fine powder.

It is further possible to treat a shaped article made from a deconstructurized starch and zein with the silanes of formula (I) to render its surface water-repellent. The shaped article is dipped or wetted in any suitable manner with the silane dried and heated to react the surface with the added silane, optionally in the presence of a catalyst as mentioned above.

The following examples further explain the invention.

#### Example 1

##### (a) Preparation of deconstructurized starch granules.

Natural potato starch, a lubricant/release agent (hydrogenated fat) and a melt flow accelerator (lecithin), are mixed together in the relative proportions in a powder mixer for 10 minutes so that a composition consisting of 81,3 parts of natural potato starch, one part of the hydrogenated triglyceride containing the fatty acid  $C_{18}$ :  $C_{16}$ :  $C_{14}$  in a ratio of 65:31:4 weight percent, 0.7 parts lecithin, and 17 parts water in the form of a freely flowing powder is obtained. This material was then fed to the hopper of an extruder. In the screw barrel the powder was

melted. The temperature within the barrel was measured to be 175°C, the average total residence time was 12 minutes (approx. 10 minutes heating time, approx. 2 minutes in molten state) and the pressure generated was equal to the vapour pressure of the moisture present in the volume of the extruder barrel. The melt was then extruded, and cut into granules of an average diameter of 2 to 3 mm. The material was hard, white with a fine foamed structure. The water content was 12%, as water was allowed to escape when the melt left the extruder nozzle. The obtained granulated material was then conditioned to a water content of 17%.

(b) Preparation of destructurized starch granules of de-bridged potato starch.

600 g of native potato starch were suspended in 700 ml of 0.2N HCl and stirred for 10 minutes. The suspension was filtered and the starch washed on the filter three times with 200 ml portions of 0.2N HCl. The starch was again suspended in 500 ml 0.2N HCl, stirred again for 10 minutes, filtered, washed three times with 200 ml portions of 0.2N HCl.

After this treatment with HCl the excess of acid was removed by washing with demineralized (deionized) water in the following way: the starch was washed twice with 200 ml portions of deionized water and then suspended in 500 ml of deionized water. This washing procedure with deionized water (to remove excess acid) was repeated twice to get the starch free of HCl. This was controlled by adding silver nitrate to the washing water. When there was no more silver chloride precipitating in the washing water, the washing was completed. The washed starch was pressed on the filter



and dried in a conditioning room (25°C, 40% RH) until it equilibrated at about 17.0% H<sub>2</sub>O.

Analysis have been carried out before and after the acid washing of starch and results obtained showed that the Ca<sup>+2</sup>-ions bridging the phosphate groups were essentially removed.

(c) Injection molding of a mixture of destructured starch and zein.

The granules as obtained under (a) and (b) above are mixed with zein in the weight ratios (i) 99.5:0.5; (ii) 99:5; (iii) 90:10 and (v) 80:20; (iv) 85:15, and injection molded to produce test pieces suitable for testing their physical properties (stress/strain behaviour) on an INSTRON tensile testing apparatus, as well as their desintegration time in water. Good results were obtained.

The term "rest" is used in this specification to represent a chemical group or radical.

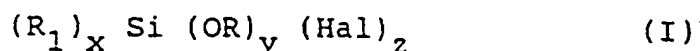
Claims

1. A polymeric material characterized in that said polymeric material is obtained by forming a melt of a water-containing destructurized starch and zein.
2. A method of producing a modified destructurized starch as claimed in claim 1 by heating a starch having a water content of 5 to 30% by weight based on the starch/water composition in a closed volume to elevated temperatures thereby at elevated pressures for a time long enough to form a melt, characterized in that said process is carried out in the presence of zein admixed to said water containing starch.
3. A process according to claim 2, wherein the starch is present in an amount of at least 70% and preferably in the range of 80-99,5% by weight of the enteric composition.
4. A method according to the claims 2 or 3, wherein said starch is selected from chemically essentially non-modified starch being carbohydrates of natural, vegetable origin composed mainly of amylose and/or amylopectin, preferably potatoes, rice, tapioca, corn, rye, oats, wheat; physically modified starch; starch with a modified acid value (pH); starch, in which the divalent ions bridging the phosphate groups have been eliminated from this bridging function; and/or pre-extruded starches.

5. A method according to the claims 2 to 4, wherein said starch is heated for destructurization in a closed volume for a time long enough to effect destructurization to a temperature within the range of about 120°C to 190°C, preferably within the range of 130°C to 190°C.
6. A method according to anyone of the claims 2 to 5, wherein pressure is applied in the range of from zero to  $150 \times 10^5 \text{ N/m}^2$ , preferably from zero to  $75 \times 10^5 \text{ N/m}^2$  and particularly from zero to  $50 \times 10^5 \text{ N/m}^2$ .
7. A method according to anyone of the claims 2 to 6, wherein the starch/zein composition has a water content in the range of about 10 to 20% by weight of the composition, preferably 12% to 19% and especially 14% to 18% by weight, calculated to the weight of the composition.
8. A method according to anyone of the claims 2 to 7, wherein the starch/zein composition according to this invention is heated to a temperature within the range of about 80 to 200°C, preferably within the range of about 120°C to 190°C and especially at about 140°C to 175°C.
9. A method according to anyone of the claims 2 to 8, wherein the starch/zein composition contains extenders, fillers, lubricants, plasticizers and/or coloring agents.
10. A method according to claim 9, characterized in that there is added at least one extender or a mixture or extenders within the range of up to

50%, preferably within the range of 3% to 10%, based on the weight of all components.

11. A method according to claims 9 or 10, characterized in that there is added at least one organic filler or a mixture of such fillers in a concentration of about 0.02 to 3%, preferably 0.02 to 1%, by weight of all components.
12. A method according to anyone of the claims 9 to 11, wherein there is added a plasticizer within the range of about 0.5 to 15%, preferably 0.5 to 5% by weight of all components.
13. A method according to anyone of the claims 9 to 12, wherein a coloring agent is added in a concentration of about 0.001 to 10%, preferably 0.5 to 3% by weight of all components.
14. A method according to anyone of the claims 9 to 13, wherein a plasticizer is added and the sum of the plasticizer and water contents does not exceed 25%, and preferably does not exceed 20% by weight of all components.
15. A method according to anyone of the claims 2 to 14, wherein a reactive silane is added in an amount within a concentration of one molecule of silane to 1000 anhydro glucose units (AGU), preferably between 2 to 50 and preferably 5 to 20 molecules of silane to 1000 AGU.
16. A method according to claim 15, wherein the silane added corresponds to the formula



wherein

$R_1$  is independently alkyl ( $C_1 - C_8$ ), substituted alkyl ( $C_1 - C_4$ ), vinyl or phenyl, wherein the alkyl substitution is selected from chlorine,  $-NH_2$ , substituted amino, an unsaturated bond or a rest carrying an epoxigroup; R is hydrogen or alkyl ( $C_1 - C_4$ ) or acyl ( $C_1 - C_4$ ), preferably methyl or ethyl, Hal is halogen, preferably chlorine, bromine, preferably chlorine;

x is 1, 2 or 3 preferably 1 or 2;

y is zero, 1, 2, or 3;

z is zero, 1, 2, or 3

the sum of y + z is 1, 2, or 3, preferably 2 or 3; and

the sum of x + y + z is 4.

17. A method according to claim 16, wherein silanes of the formula (I) are used wherein x is 1 or 2, preferably 1; R is methyl or ethyl, preferably methyl and  $R_1$  is methyl, ethyl propyl, butyl; and z is zero.
18. A method according to anyone of the claims 2 to 17, wherein there is added to the starch at least one active ingredient selected from pharmaceuticals and/or agriculturally active compounds.
19. The melt obtained according to anyone of the claims 2 to 18.

20. The solidified destructureized starch obtained by cooling the material obtained according to claim 19.
21. The use of modified starch zein compositions, obtained as claimed in anyone of the claims 2 to 20 as carrier material for active ingredients, preferably as carrier materials for pharmaceuticals, and/or agriculturally active substances.
22. The process of shaping a destructureized starch zein composition as obtained according to anyone of the claims 2 to 21, under controlled water content and pressure conditions as a thermoplastic melt wherein said shaping process is at least one member selected from the class consisting of injection molding, blow molding, extrusion and coextrusion, compression molding or vacuum forming.
23. Shaped articles produced from a composition obtained by the method as claimed in anyone of the claims 2 to 22.
24. The articles of claim 23, wherein said articles have been shaped as bottles, sheets, films, packaging materials, pipes, rods, laminates, sacks, bags or pharmaceutical capsules, granules or powders.
25. A water-repellent article made from a destructureized starch/zein composition obtained by treating its surface with a silane compound according to the claims 15 to 17.